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DURABILITY OF GEOSYNTHETICS IN WASTE MANAGEMENT FACILITIES: NEEDED RESEARCH

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ABSTRACT

The United States Environmental Protection Agency is interested in both the short- and long-term performance of geosynthetics when these materials are used in waste management facilities. This paper discusses research to address both concerns and identifies data gaps that require additional research.

INTRODUCTION

The U.S. Environmental Protection Agency has been mandated by Congress to develop standards to manage both hazardous and nonhazardous wastes in this country in a manner protective of human health and the environment. The EPA, through its research and experience in field activities continues to refine the control strategies by incorporating state-of-the-art materials in design alternatives for improving the performance of waste management facilities. The use of geosynthetics (flexible membranes, geotextiles, geonets, and plastic pipes) is playing an increasing role in these control strategies. Although a significant amount of research, both government and private, has been performed on short-term performance issues, relatively little is devoted to the long-term performance of these materials. This paper discusses two issues relating to the durability of geosynthetics used in waste containment: durability as related to design and installation and durability as related to longevity.

INSTALLATION

Background

Using geosynthetics to contain wastes is a relatively new technology-emerging in the last 5 to 10 years. In early installations, primarily in the western United States, the materials were used to contain water.

Designed to minimize loss of water to the environment, these installations achieved remarkable success and soon gained wide acceptance. If water were lost, the adverse effect was monetary, not necessarily environment.

Farsighted engineers, realizing that wastes and leachates should be contained, designed ponds to contain effluents from the food processing industry and municipal solid waste landfills. A certain leakage (permeability) was inevitable with the natural soils that were used as the only barriers in these installations. Geosynthetics had the potential to provide a leak-free lining if properly installed. The lining industry was, however, growing and questions were asked: how does one select a suitable polymer material from the many that are available? what tests are required? how do we install the material in the field?

EPA Research

EPA's initial research efforts were directed at resolving these questions. Two- to five-year research projects were started to determine if these materials would survive exposure to leachates from both hazardous and nonhazardous waste. It soon became evident the resistance of the liners varied with the quality of the waste and with the type of liner material. It became evident also that a short-term test was needed to model or predict long-term performance. From these series of research projects, EPA's standard "Method 9090" immersion test was developed to evaluate the chemical resistance of polymeric materials. For 120 days, candidate materials are exposed (at room temperature and at an elevated temperature) to the waste that they are to contain. Specific physical properties are tested on a monthly basis, and the resulting data are evaluated for rates of change over this period of time. Data from short-term tests have been compared to field verification data, and although additional data are needed, the results are encouraging.

Other research projects addressed installation problems such as soil bedding characteristics (both size and thickness), environmental site conditions (temperature, humidity, wind, etc.), seaming techniques, and others. The studies proved difficult because of the wide variety of liner materials and thicknesses used and inevitability of varying workmanship with different contractors. Again, what types of tests could be developed to provide information on the quality of installation? The questions multiplied when geotextiles and geonets were introduced to help alleviate soil bedding problems and to provide improved drainage capabilities.

Although EPA developed guidance documents on installing membranes and on evaluating seaming, the single most important document was on construction quality control and quality assurance.* The overall intent of this document was to identify the responsibilities of the designers of the facility and those of the builders and to encourage a dialogue between them. The objective of the document was to increase the probability that the facility would perform as well or better than the design.

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*USEPA (1986) Technical Guidance Document: Construction Quality Assurance for Hazardous Waste Land Disposal Facilities. Cincinnati, OH. EPA/530/SW-86-031.

Questions facing the waste management industry concerned designing the facility. How thick should the geosynthetic be? What function do these materials have? What are the stresses during and after installation? Waste management design engineers were being educated about geosynthetics and were becoming comfortable with their use. To answer concerns of what test or tests to use, which model will estimate actual conditions, and how to develop both short- and long-term field verifications, a design manual was developed based on the civil engineering free-body diagrams. From the manual, stresses can be calculated for a variety of design scenarios, these calculated stresses can be compared with the physical properties of the geosynthetic, and a design ratio can be developed. The design ratio is defined as the ratio of the allowable material performance divided by the actual material service condition calculated. A design ratio of one is required to prevent an undue amount of stress or strain on the component. Since the performance limit of the materials or the service conditions can't be accurately predicted or defined design ratios greater than one are used to ensure satisfactory performance. Design ratios should be high until the models (free-body diagrams) are field verified.

LONGEVITY AND STRESS

In any discussion on the use of geosynthetics the question will eventually be raised about how long these materials will last. Although the durability of geosynthetics remain uncertain, more must be known about the aging characteristics of the polymeric materials from which they are made as they function in modern waste disposal environments.

The Membrane in the Landfill Environment

During the active life of a municipal solid waste landfill, the flexible membrane liner (FML) in the bottom liner system will be exposed to a temperature between 40° and 70°F, a constant flow of leachate on the top liner, no light, an atmosphere that might vary between aerobic and anaerobic, many kinds of bacteria in the probably slightly acidic leachate, and a great overburden pressure in a deep landfill. After closure with the final cover system in place, the amount of leachate will gradually diminish. Although the load on the FML in the final cover system will not be great, the coefficient of friction between the soil and the FML could be significant causing mechanical damage.

In a hazardous waste landfill, the FML will not only be exposed to the kinds of conditions found in a municipal solid waste landfill but also to the organics that are more aggressive to polymeric materials than are the constituents of municipal landfill leachates. Moreover, in a hazardous waste landfill, there will probably be increased microbial action, if the waste doesn't kill the microbes. A hazardous waste landfill generates less gas because of the wastes characteristics and toxicity and there's also less consolidation of waste in a hazardous waste landfill than in a municipal solid waste landfill.

Ultimately, the stresses encountered during construction, operation, and post operation determines the longevity of a polymer. During construction, the polymeric components could be exposed to too much heat or sunlight, stored too long, scratched or gouged, loaded or strained to

excess, or folded. Such damage may not be apparent at final inspection. Or, during operation, the organics in a hazardous waste landfill could permeate the FML and could be absorbed by geotextiles and geonets used in drainage systems. The softened drainage materials plus the overburden on the drainage system could reduce its capacity, depending on the polymeric drainage basic resin and design. Or microbial action, which could help degrade the landfill's contents, could result in fungal growth that could biologically degrade and/or clog the drainage system. Or, after a landfill is closed, soil, wet from a heavy rain, could slip on the surface and expose the final FML cover. Or, as the municipal solid waste consolidates unevenly over time, the strain could result in breaks in the cover FML after closure.

Such conditions, and more, will affect service life. What is needed, then, is carefully handled, highly rugged polymer materials that withstand the continuing stresses of the landfill environment: chemical, mechanical, biological, and combined chemical/mechanical stresses.

Chemical Stresses

Before, during, and after operation of a landfill, the polymers used in construction of containment systems can break down, swell, increase in crystallinity, or lose ingredients. These conditions have been observed in materials removed from service.

The polymer can break down when oxygen reacts with the polymer to cause cross-linking or scission of polymer chains; or when, after lengthy, improper storage, UV light reacts with the polymer to cause scission of polymer chains; or when the heat from thermal-based seaming causes the polymer to degrade.

The polymer can swell and soften when it absorbs organics. Short-term exposure probably does not affect polymer integrity, but there is no knowledge about the long-term combined effects of softening and mechanical stresses. Part of this lack of knowledge about long-term effects includes the effect of creep, particularly concerning FML's and synthetic drainage media. Although some factors apply only to certain polymers, the amount of particulate filler, or the amount of plasticizers, or the amount of water soluble inorganic salts or other additives may all cause polymer swelling.

With an increase in crystalline content, semicrystalline polymers could become embrittled and have lowered resistance to stress cracking. Again, little knowledge exists about the effect of long-term exposure of semicrystalline polymers to landfill environments.

The service life of a polymer could be reduced through a leachate extracting the compounding ingredients from the product. Such selective extraction would depend on the polymer's composition and the composition of the waste and leachate.

Mechanical Stresses

Before, during, and after operation of a landfill, polymers used in their construction can crack, the drainage system can be subjected to mechanical/ chemical creep, or the mechanical components can be incompatible.

Flaws in FML sheeting can initiate cracks--slow-crack-growth failure or stress-crack type failures. The flaws can result from scratches, seaming operations, a change in polymer thickness, etc. Scratches and cracking can be minimized through proper use of bedding, development of better engineering designs, and in the case of polyethylene, optimized use of co-monomers, crystallinity, and molecular weight.

Another unknown is the creep of a polymer drainage system under constant stress. How well can the new polymer drainage system components stand up to long-term loadings and what is the effect of compressive creep that results in transmissivity loss? When combined with exposure to organics, a system could completely collapse.

The use of "foamed" geonets (those with gas-filled bubbles in the net) should be discouraged because the geonet can collapse as the gas is slowly released.

Mechanical incompatibility problems (e.g., fine-clogged leachate collection network; too-thin FML intruding into open spaces of drainage media; compacted clay liner above the FML and the drainage system in a double composite lining system damaging either system; clay particles in the clay components of a double composite lining system clogging the filter) can be prevented by use of existing guidance and by continued evaluation and development of standard engineering protocols.

Biological Stresses

A polymer's resistance to biological activity, particularly that of the drainage media, could determine a liner system's ultimate service life. The polymers used in manufacturing FML's are usually very resistant to biodegradation, although some additives may not be. While most bio-resistant polymers may not degrade for centuries, if at all, biological growth that can take place on the surface can clog leachate drainage and collection systems rendering them useless.

Leachate collection and removal systems are required above the top liner and between the top and bottom liners. If the collection and removal system above the top liner fails, the hydraulic head is not controlled. If the system between the liner fails, is the top liner breached and/or is leachate ponding on the bottom liner?

Biological growth which can cause the leachate collection and removal system to fail, is a potential problem in both municipal solid waste and hazardous waste landfills. To prevent clogging by microorganisms that can attach to and grow on drainage media or develop by a sedimentation mechanism, suggested solutions include:

--using compounds with very low surface energy for the drainage media;

--incorporating a biocide into the drainage media compound;

--coating the drainage media and FML with biocides; or

--flushing the drainage system with biocides.

Each suggestion, however, has its limitations.

Combined Stresses

Chemical and mechanical stresses can combine to affect the polymer's service life. Because chemical exposure can change the composition, the mechanical properties of the geosynthetic can change.

The combined stress on semicrystalline (and possibly noncrystalline) polymeric materials can cause stress cracks. (This may be the most serious deficiency of HDPE liners.)

Properties such as average molecular weight, molecular weight distribution, branch length, and crystallinity content all influence environmental stress cracking in polymers. Factor affecting these properties will likewise affect the resistance to environmental stress cracking. It is known, for example, that the higher the molecular weight and the wider the molecular weight distribution, the higher this resistance. Moreover, the chemical environment, the presence of scratches and seams in an FML, and stress levels caused by manufacture or installation also affect environmental stress cracking.

Because polyethylene FML's have been used only recently, little is known of long-term exposures, i.e., 20 years, and whether the stress cracks develop as a result of flaws in design and construction procedures, and/or chemical environmental exposure.

Clogging of drainage nets by fines is possible, but clogging should not be a problem if proper attention is given to design and quality control. On the other hand, chemical precipitation or deposition resulting from biological activities or interaction between drainage stone and waste leachate can clog granular filters, e.g., iron oxides from rusty containers can cement granular drainage media together, as can carbonates from microbial activity.

Summary of Factors Affecting Longevity

Polymers (polyethylenes, modified olefinic polymers, and some polyesters) used in liner systems do not encounter conditions normally considered to cause degradation of the base polymeric resins. Although the polymers discussed should maintain their integrity for probably hundreds of years, they are subject to chemical, mechanical, and combined stresses that may deteriorate some important properties in shorter times.

The scope of concerns about the service life of landfill polymers encompasses:

--stresses (combined mechanical and chemical) due to environmental stress-cracking or mechanical fatigue that may cause failure;

--swelling and softening of polymeric components due to absorbed waste constituents combined with an overburden load that may cause creep-induced damage to the drainage, collection, and detection systems;

--extraction, volatilization, or biodegradation of polymer additives over a long term may cause loss of plasticized polymeric materials;

--biological growth or sedimentation and/or precipitation of dissolved constituents that may cause drainage and detection systems to clog; and

--seaming of FML's-because no test method truly assesses the effects of long-term exposure.

Short-and Long Term Research Needs for Durability

With all the research and field work that both the government and industry has done, the short-term durability of geosynthetics still presents unanswered questions. The information data base is improved, but newer products and designs require additional attention.

Improvements in short-term durability are needed. We need more information on chemical resistance, especially for geosynthetics other than membranes. Although Method 9090 is used for hazardous waste, we need to know whether the same type of test is needed for nonhazardous waste. Additional field verification is needed for the models used to evaluate actual field stress/strain conditions. Detailed construction quality assurance/quality control procedures are needed. Improved installation techniques to minimize stress and to improve seaming are needed. As new designs are developed, additional concerns will be generated.

To prevent the potential degradation of geosynthetic system components, research on long-term effects must be continued. Foremost is field verification studies, including long-term research and autopsies of sites being decommissioned, to extend the laboratory and pilot-scale data bases. The improvement in construction/installation activities must continue to minimize stresses, and quality assurance programs must continually be upgraded to ensure materials are not installed beyond their design limits. Material quality to improve long-term durability should be researched.

CONCLUSIONS

The use of geosynthetics in waste management facilities have improved the performance capability of managing a variety of wastes. Facilities now being constructed with these materials should not present environmental problems that have been associated with older designs. Durability, both short- and long-term, for geosynthetics used in waste management facilities should be considered high priority research. As new materials are developed and new designs for these facilities are proposed, we must have performance tests available for evaluation. While we are starting to accumulate a wealth of information on short- and long-term performance, the greater challenge lies ahead. Working together, industry and government programs will develop the necessary design and construction procedures that will enhance the use of geosynthetics while protecting human health and the environment.